

**DATA PROCESSING SYSTEM AND METHOD OF COMMUNICATION THAT
EMPLOY A REQUEST-AND-FORGET PROTOCOL**

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BACKGROUND OF THE INVENTION

1. Technical Field:

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The present invention relates in general to data processing and, in particular, to communication in a data processing system. Still more particularly, the present invention relates to a data processing system and method of communication utilizing a "request-and-forget" protocol.

2. Description of the Related Art:

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At a conceptual level, a data processing system can be thought of as a collection of interconnected components, each comprising hardware and/or software and/or firmware, which operate in concert to process information. Because each component of the data processing system has a limited range of functionality circumscribed by its circuitry and/or programming as well as a finite amount of data storage, components must frequently make requests for service by other components of the data processing system in order to accomplish the necessary work.

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Data processing systems nearly universally manage such requests by implementing queues to buffer requests at each of the requestor component (also referred to as master or client) and the recipient

component (also referred to as slave or server). In a typical management scheme, the requestor allocates a queue entry to a request and maintains the queue entry allocation until the requestor receives an acknowledgment of service (and perhaps data associated with the request) from the recipient. The requestor removes the request from the queue only after receiving the acknowledgment, meaning that the allocated queue entry cannot be utilized for processing another request until the current request has been retired. Consequently, the maximum number of requests undergoing processing at any one time is equal to the queue depth of the requestor.

To avoid the requestor overflowing the queues of the recipient, it is often required for the requestor to have intimate knowledge of the queue capacity of the recipient, the latencies associated with the transmission of requests and acknowledgments between the requestor and the recipient, the number of types of possible requests and acknowledgments, and so forth. The requirement that the requestor have knowledge of the internal design of the recipient, the communication latency, the possible information types, etc., limits the flexibility of system design and may require the incorporation of a large number of configuration fields or the like into the design of the requestor to indicate the recipient's configuration. With such limitations and complexity present in each requestor/recipient pair, data processing system design tends to be either undesirably inflexible or complex or both.

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[illegible]

SUMMARY OF THE INVENTION

A data processing system in accordance with the present invention includes a requestor having a request queue and a recipient. The requestor, which buffers a request in an entry of the request queue, transmits the request to the recipient for servicing. According to the request-and-forget protocol, the requestor removes the request from the entry of the request queue without receipt of any indication that the request has been serviced.

All objects, features, and advantages of the present invention will become apparent in the following detailed written description.

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BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 depicts an illustrative embodiment of a data processing system in accordance with a preferred embodiment of the present invention;

Figure 2A is a high-level logical flowchart of the operation of a requestor (which in the data processing system embodiment shown in **Figure 1** is L3 request controller **22**) that employs a request-and-forget protocol in accordance with the present invention;

Figure 2B is a high-level logical flowchart of the operation of a recipient (which in the data processing system embodiment shown in **Figure 1** is L3 data chip **18**) that employs a request-and-forget protocol in accordance with the present invention;

Figure 2C is a high-level logical flowchart of a method of communicating request responses from a recipient to a response receiver in accordance with the request-and-forget protocol of the present invention;

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D E P O S I T

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference now to the figures and in particular with reference to **Figure 1**, there is illustrated a high-level block diagram of an exemplary data processing system that employs a request-and-forget protocol in accordance with the present invention. As depicted, data processing system **8** includes at least one and possibly multiple snoopers **10a-10n** coupled to an interconnect fabric **12**. Interconnect fabric **12**, which can comprise one or more buses but preferably comprises an integrated switch, serves as a conduit for communication between the snoopers **10** coupled to interconnect fabric **12**. A typical transaction on interconnect fabric **12** begins with a request, which may include a transaction type, source and destination tags indicating the source and intended recipient(s) of the transaction, respectively, and an address and/or data. Snoopers **10** snoop requests on interconnect fabric **12** and, if appropriate, respond to the request with a snoop response. The various snoop responses are utilized to determine what action, if any, snoopers **10** are to take to service the request. Servicing the request may entail sourcing data to the requestor on interconnect fabric **12**, storing data provided by the requestor, etc.

In the illustrated embodiment, snoopers **10a** comprises an integrated circuit processor complex including one or more processors **14**. Processor(s) **14** have an associated on-chip cache hierarchy **16**, which includes, for example, one level-one (L1) and one level-

two (L2) cache for each processor **14**. Processor(s) **14** also have one or more associated lower levels of off-chip cache memory, such as that provided by L3 data chip **18**, and, at the lowest level of the memory hierarchy, a system memory **20**. As understood by those skilled in the art, each succeeding lower level of the memory hierarchy is typically capable of storing a larger amount of data than higher levels, but at higher access latency.

Processor complex **10a** interfaces with L3 data chip **18** via an on-chip L3 request controller **22**, which includes a request queue **24** containing a plurality of queue entries **26**. Similar to the interconnect requests discussed above, the requests buffered within request queue **24** may include, for example, a source tag identifying the source of the request, a request address, a transaction type specifying the desired operation on the data identified by the request address, and optionally data. Based upon the request address, L3 request controller **22** determines whether queued requests can be satisfied by either L3 data chip **18** or system memory **20**. For example, L3 request controller **22** may determine whether system memory **20** can service a queued request by comparing the request address to a memory map specifying the address ranges assigned to system memory **20** and can determine whether L3 data chip can service a request by reference to an on-chip L3 directory **28** that records addresses associated with the data stored in the arrays **40** of L3 data chip **18**. If L3 request controller **22** determines that a request cannot be serviced by L3 data chip **18** or system memory **20**, L3 request controller

22 may drop the request or, alternatively, pass the request to an interface unit 34 of processor complex 10a via request line 36 for subsequent transmission to another snoopers 10 via interconnect fabric 12. If, however, L3 request controller 22 determines that a request can be serviced by L3 data chip 18 or system memory 20, L3 request controller 22 transmits the request to L3 data chip 18. L3 request controller 22 preferably appends or sets a bypass field for requests destined for system memory 20 to indicate to L3 data chip 18 that such requests should be passed to system memory 20 for processing.

The interface between L3 request controller 22 and L3 data chip 18 includes request lines 38 for communicating requests to L3 data chip 18 and status line(s) 39 by which L3 data chip 18 informs L3 request controller 22 that L3 data chip 18 cannot currently accept additional requests. Thus, in contrast to prior art controller interfaces, which typically generate explicit row, column and address strobes to control the operation of a memory slave, the interface between L3 request controller 22 and L3 data chip 18 provides a high degree of device independence in that L3 request controller 22 is not restricted to use with data chips having any particular internal configuration.

The depicted embodiment of L3 data chip 18 contains a data chip controller 42 and a plurality of arrays 40 for caching data. Each array 40 has an associated set of array queues 44 from which requests are

serviced by the associated array **40**. As shown in **Figure 3**, each array queue entry **180** may include a transaction type field **182**, a source tag field **184**, an address field **186**, and a data field **188**. Each array queue entry **180** also preferably has an associated serviced flag **190** to indicate to data chip controller **42** when the request contained therein has been serviced, and may optionally have additional associated flags, as discussed further below.

As illustrated, data chip controller **42** includes a decoder **46** that passes requests having a set bypass field to system memory **20** and that assigns the remaining requests to the appropriate array queues **44** for servicing. In a preferred embodiment in which each set of array queues **44** contains a respective array queue **44** (or a respective allocation of queue entries from a shared pool of queue entries) for each type of request, decoder **46** selects an array **40** to service a request based upon the request address and assigns requests to an array queue **44** associated with the selected array **40** based upon the transaction type. Array circuitry (not illustrated) associated with arrays **40** service requests enqueued in their respective set of array queues **44** and, if the request is a Read or other request for data, store the requested data in the array queue entry in conjunction with the request. The serviced request (or response) may thus include the same fields as a request, and optionally one or more additional fields. The serviced flag **190** is set to indicate when a request has been serviced.

As shown, data chip controller **42** also includes an arbiter **48** that governs which serviced requests are retired from array queues **44**. Although arbiter **48** can prioritize serviced requests to be retired based upon any one or combination of selection methods, including static selection methods (e.g., random or round robin) or dynamic selection methods (e.g., based upon the number of total requests or serviced requests in each of array queues **44**), arbiter **48** preferably additionally prioritizes which serviced requests are retired based upon an imprecise priority signal **50**, which processor complex **10a** utilizes to specify one or more favored transaction types for which responses are desired. Priority signal **50** is said to be imprecise in that arbiter **48** can select a different type of transaction(s) than that specified by priority signal **50** without causing improper system operation.

Referring again to processor complex **10a**, interface unit **34** comprises an interface controller **52**, a pool of inbound queues **60** for temporarily buffering inbound requests and responses received from interconnect fabric **12**, a pool of outbound queues **62** for temporarily buffering outbound requests and responses for transmission on interconnect fabric **12**, and a plurality of input and output ports **64** and **66** by which requests and responses are communicated with interconnect fabric **12**. Interface controller **52** preferably dynamically sets and adjusts the number of entries in inbound and outbound queues **60** and **62** that may be allocated to requests and responses of each transaction type. Interface controller

52 indicates to arbiter 48 when no more requests of a given type can be received via status lines 72.

As shown, interface controller 52 includes priority logic 54, which generates priority signal 50 based upon inputs such as the number of entries within inbound queues 60 and outbound queues 62 allocated to each type of transaction, the queue size allocated to each transaction type, a system monitor input, etc. Interface controller 52 further includes a decoder 56 that receives request responses (i.e., serviced requests) from arbiter 48 via response lines 70 and, based upon the transaction type and source specified by the responses, forwards the request responses to either cache hierarchy 16 or one of outbound queues 62. For example, decoder 56 passes responses to Read requests specifying cache hierarchy 16 as a source to cache hierarchy 16, but forwards responses for Read requests specifying another snooper 10 as the source to one of outbound queues 62.

Those skilled in the art will appreciate that data processing system 8 can include many additional unillustrated components, such as interconnect bridges, non-volatile storage, ports for connection to networks or attached devices, etc. Because such additional components are not necessary for an understanding of the present invention, they are not illustrated in **Figure 1** or discussed further herein. It should also be understood, however, that the enhancements provided by the present invention are generally applicable to communication within and between data processing systems

of any architecture and is in no way limited to the generalized data processing system architecture illustrated in **Figure 1**.

5 With reference now to **Figures 2A-2D**, there are depicted a series of high-level logical flowcharts that together illustrate an exemplary implementation of a request-and-forget protocol for communicating requests and responses between a requestor, a recipient and a response receiver in accordance with the present invention. The flowcharts will be described with reference to data processing system **8** of **Figure 1**, in which L3 request controller **22**, data chip controller **42** and interface controller **52** serve as the requestor, recipient and response receiver, respectively. As will be appreciated from the following description, **Figures 2A-2D** illustrate logical sequences of steps, which may be performed concurrently or, in some cases, in an alternative order.

Referring first to **Figure 2A**, there is illustrated a high-level logical flowchart of the operation of a requestor (which in the data processing system embodiment shown in **Figure 1** is L3 request controller **22**) that employs a request-and-forget protocol in accordance with the present invention. As shown, the process begins at block **90** and then proceeds to block **92**, at which point L3 request controller **22** begins processing on a request queued in an entry **26** of request queue **24**. Block **92** depicts L3 request controller **22** determining whether or not the request should be passed to L3 data

chip **18** for processing. As discussed above, the determination illustrated at block **92** can be made by reference to a memory map, which specifies the addresses assigned to system memory **20**, and to L3 directory **28**, which specifies which data are cached in arrays **40** of L3 data chip **18**. If L3 request controller **22** determines at block **92** that the request should not be passed to L3 data chip **18** for processing, then the process illustrated in **Figure 2A** passes to block **94**, which illustrates L3 request controller **22** dequeuing the request for processing and, for example, transmitting the request to interface controller **52** via request line **36**. The process then terminates at block **100**.

Returning to block **92**, in addition to a determination that the queued request should be passed to L3 data chip **18** for processing, a determination is made at block **96** whether data chip controller **42** has signaled via status line(s) **39** that queue entries are available to receive requests. If L3 request controller **22** determines that the queued request should be passed to L3 data chip **18** for processing and that no queue entry for the request is currently available, then L3 request controller **22** waits until data chip controller **42** indicates via status line(s) **39** that a queue entry has become available, as shown by the process iterating at block **96**. When a queue entry is available, L3 request controller **22** transmits the request to data chip controller **42** of L3 data chip **18** via request lines **38** and dequeues the request from request queue **24**. Thus, in contrast to prior art request

protocols, which retain a request in a queue entry until the request is serviced, the request-and-forget protocol of the present invention dequeues the request upon successful transmission, freeing the associated queue entry to be allocated to a new request. Thereafter, the process illustrated in **Figure 2A** terminates at block **100**.

With reference now to **Figure 2B**, there is depicted a high-level logical flowchart of the operation of a recipient (which in the data processing system embodiment shown in **Figure 1** is data chip controller **42** of L3 data chip **18**) that employs a request-and-forget protocol in accordance with the present invention. As illustrated, the process begins at block **110** in response to receipt of a request from L3 request controller **22** via request lines **38**. The process then proceeds to block **112**, which illustrates data chip controller **42** determining whether or not the bypass field is set in the request to indicate that the request is intended for system memory **20**. In response to a determination that the bypass field is set in the request, the process proceeds to block **114**, which illustrates data chip controller **42** passing the request to system memory **20** for servicing. The process thereafter terminates at block **122**.

Referring again to block **112**, in response to a determination that the bypass field is not set in the request, the process proceeds to block **116**, which depicts decoder **46** of data chip controller **42** decoding the request's address and transaction type and enqueueing the

request in the relevant array queue **44** of the appropriate array **40**. Data chip controller **42** next determines at block **118** whether or not enqueueing the request filled the array queue **44** such that additional requests of the same type cannot now be received. If not, the process terminates at block **122**. However, if enqueueing the request fills an array queue **44**, the process passes to block **120**, which illustrates data chip controller **42** indicating to L3 request controller **22** via status lines **39** that additional requests of the same type as the last request cannot now be received. As will be appreciated by those skilled in the art, additional and more specific information such as the array **40** having the full array queue **44** can be provided to reduce unnecessary stalls. Following block **120**, the process illustrated in **Figure 2B** terminates at block **122**.

Referring now to **Figure 2C**, there is illustrated a high-level logical flowchart of a process employed by the recipient (which in the data processing system embodiment shown in **Figure 1** is data chip controller **42**) to communicate serviced requests to the response recipient (e.g., interface controller **52**) in accordance with the request-and-forget protocol of the present invention. It can be seen by comparison of **Figure 2C** with **Figure 2A** that the process is nearly identical to that employed by L3 request controller **22** to communicate requests to data chip controller **42**.

As illustrated, the process begins at block **130** and then proceeds to block **132**, at which point processing

begins on a serviced request queued in an entry of an array queue **44**. As noted above, serviced requests are preferably identified by the setting of the serviced flag **190** associated with the queue entries. As also mentioned above, data chip controller **42** can select the serviced request for processing based upon one or multiple inputs, including the imprecise priority signal **50** provided by priority logic **54**.

As shown at blocks **132** and **134**, if the request is the type that does not require a response (e.g., a Write or Kill), data chip controller **42** simply dequeues the request, freeing the queue entry for allocation to another request. However, if the request requires a response, the process passes to block **136**, which represents a determination of whether interface controller **52** has signaled via status line(s) **72** that a queue entry is not available to receive responses of the type under consideration. If so, then data chip controller **42** waits to transmit the response until interface controller **52** indicates via status line(s) **72** that a queue entry has become available, as shown by the process iterating at block **136**. (During this waiting period, data chip controller **42** can transmit responses of different types to interface controller **52**.) When a queue entry is available to receive the response, data chip controller **42** transmits the response to interface controller **52** via response lines **70** and dequeues the request from request queue **24**. Thereafter, the process illustrated in **Figure 2C** terminates at block **140**.

With reference now to **Figure 2D**, there is depicted a high-level logical flowchart of the operation of a response receiver (which in the data processing system embodiment shown in **Figure 1** is interface controller **52**) that employs a request-and-forget protocol in accordance with the present invention. As can be seen by comparison of **Figure 2D** with **Figure 2B**, the process illustrated in **Figure 2D** is very similar to that performed by data chip controller **42** when receiving requests from L3 request controller **22**.

As illustrated in **Figure 2D**, the process begins at block **150** in response to receipt of a response from data chip controller **42** via response lines **70**. The process then proceeds to block **152**, which illustrates decoder **56** determining whether the source of the request was cache hierarchy **16** or one of snoopers **10b-10n**. In response to a determination that the source of the request was cache hierarchy **16**, the process proceeds to block **154**, which illustrates interface controller **52** passing the response to cache hierarchy **16** for processing (e.g., caching requested data). The process thereafter terminates at block **170**.

Referring again to block **152**, in response to a determination that the source of the request was one of snoopers **10b-10n**, the process proceeds to block **156**, which depicts decoder **56** of interface controller **52** decoding the transaction type and enqueueing the response in an entry of the appropriate outbound queue **62** for subsequent transmission to the request source via

interconnect fabric **12**. Interface controller **52** next determines at block **158** whether or not enqueueing the request filled all entries in outbound queues **62** that can be allocated to responses of the same type. If not, the process terminates at block **170**. However, if enqueueing the request fills all outbound queue entries that can be allocated to responses of this type (and if interface controller **52** does not dynamically allocate more queue entries in the pool of outbound queues **62** to this response type), the process passes to block **160**, which illustrates interface controller **52** indicating to arbiter **48** via status lines **72** that additional responses of the same type as the last request cannot now be received. Following block **160**, the process illustrated in **Figure 2D** terminates at block **170**.

An implementation detail not addressed in the high-level flowcharts described above concerns how the request-and-forget protocol of the present invention can be employed in data processing system embodiments in which the latency between the transmission of requests to the recipient or to the response receiver is less than the latency of the status lines. For example, if a request or response can be transmitted every other clock cycle and status indications have a latency of 10 clock cycles, it is apparent that, following transmission of a status signal, up to five requests or responses may be lost if they are dequeued upon transmission.

Several mechanisms can be employed to avert this type of data loss, including limiting the rate at

which requests and responses can be transmitted or adding an explicit request acknowledgment/retry mechanism to the requestor, recipient, and response receiver interfaces to inform the device transmitting the request or response whether a particular request or response was successfully received. It is, however, presently preferable to maintain maximum request and response rates and to avoid introducing complexity into the device interfaces. This can be accomplished while preventing data loss by utilizing a timer to delay dequeuing transmitted requests and responses from request queue **24** and array queues **44** for an interval following transmission of the request or response equal in duration to the worst-case latency of the status indication. In this manner, if L3 request controller **22** or data chip controller **42** receives a status signal, all transmitted but not yet dequeued requests or responses affected by the status indication can simply be retransmitted when the status indication is removed. As shown in **Figure 3**, transmitted requests or responses can be identified by setting a transmitted flag **192** associated with the queue entries buffering such requests or responses.

As has been described, the present invention introduces a request-and-forget protocol for communicating data (such as requests and responses) in a data processing system. In accordance with the request-and-forget protocol of the present invention, a queued request (or response) is transmitted to a recipient and, in contrast to traditional interfaces (e.g., bused interfaces) that maintain the request in the queue entry until the request is serviced, the request is removed

from the queue prior to servicing.

5 The request-and-forget protocol of the present invention has a number of attendant benefits. First, the number of requests or responses that can be "in flight" at any one time is not limited by the queue depth of the device transmitting the requests or responses. Thus, queue depths and circuit area may be reduced without diminishing performance. Second, queue depths and queue
10 entries allocations of various devices are made independent. Consequently, the allocation of queue entries to various types of requests and responses can be dynamically altered during operation of the data processing system without the need to explicitly inform any other component. Third, the request-and-forget protocol permits a wide range of flexibility in system design because a wide range of components can be utilized in the data processing system without any special configuration as long as the generic request interface is supported.

25 While the invention has been particularly shown and described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention. For example, the status lines described above can be omitted if the device sending requests or responses knows or is provided with knowledge of the
30 queue depths of the device receiving the requests or responses. More generally, although the described data processing system embodiment employs the request-and-

forget protocol of the present invention for communication between integrated circuits, it should be understood that the request-and-forget protocol is not limited merely to chip-to-chip communication. Rather, the request-and-forget protocol of the present invention can be employed, without limitation, in communication over the system interconnect (e.g., interconnect fabric **12**), communication between integrated circuits within a chip module, and communication between subcircuits of a single integrated circuit.